

TITLE OF THE INVENTION

DISPLAY DEVICE HAVING AN IMPROVED VOLTAGE LEVEL CONVERTER  
CIRCUIT

5

BACKGROUND OF THE INVENTION

The present invention relates to a display device, and in particular to an active matrix type display device having a driver circuit for driving pixels, fabricated on its substrate of its display panel.

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A display panel has an electrooptical material layer sandwiched between a pair of substrates. In this specification, the term "electrooptical material" refers to material which changes its optical properties such as transmission, emission, refractive index and absorption of light under the influence of an electric field or  
15 current. The electrooptical material includes liquid crystal material and electroluminescent material, for example.

By way of example, an active matrix type liquid crystal display device shall be considered.

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In the active matrix type liquid crystal display device, each pixel area is surrounded by two adjacent ones of a plurality of gate signal lines extending in the x direction and arranged in the y direction and two adjacent ones of a plurality of drain signal lines extending in the y direction and arranged in the x direction which are fabricated on a liquid-crystal-  
25 layer-side surface of one of a pair of substrates sandwiching

a liquid crystal layer. Each pixel area is provided with a thin film transistor operated by a scanning signal supplied from one of the gate signal lines and a pixel electrode supplied with a video signal from one of the drain signal lines via the  
5 thin film transistor.

The pixel electrode generates an electric field between it and a counter electrode fabricated on the other of the pair of substrates, for example, so that the electric field control the light transmission through the liquid crystal layer between  
10 the two electrodes. The liquid crystal display device is provided with a scanning signal driving circuit for supplying a scanning signal to each of the gate signal lines and a video signal line driving circuit for supplying a video signal to each of the drain signal lines.

15 These scanning signal driving circuit and video signal line driving circuit are formed of a large number of MIS (Metal Insulator Semiconductor) transistors having configurations similar to thin film transistors fabricated in the pixel areas, and therefore a technique is known in which semiconductor layers  
20 of the thin film transistors in the pixel areas are made of polycrystalline silicon (p-Si), and the scanning signal driving circuit and the video signal line driving circuit are fabricated on the one of the pair of substrates simultaneously with the pixels. These circuits are composed of transistors  
25 made of polycrystalline silicon, therefore their output signal

levels are low, and consequently, their output signal themselves are sometimes insufficient for driving the pixels. To solve this problem, voltage level converters are incorporated into the liquid crystal display devices for  
5 converting voltages such as pulses from a low level to a higher level. Generally, the voltage level converters as shown in FIG. 16 or FIG. 17, for example.

#### SUMMARY OF THE INVENTION

10 The basic operating principle of the above-mentioned voltage level converters is that ON-OFF of a current in one of a pair of MOS transistors of the opposite conductivity types is controlled by an external input pulse, and by using a resultant change in voltage, ON-OFF of a current in the other of the pair of MOS transistors is  
15 controlled so as to provide a pulse having an amplitude greater than that of the external input pulse. As a result, ON-OFF of the current in the other of the pair of MOS transistors is controlled by using as an input a large voltage change close to an amplitude of the level-converted voltage. Consequently, some current (hereinafter  
20 the through current) flows through the pair of MOS transistors before the voltage for controlling ON-OFF of the current in the other of the pair of MOS transistors reaches a voltage sufficient to control the ON-Off of the current.

When the voltage level converter is composed of polysilicon  
25 MOS transistors, it has been pointed out that its current supply

capability is decreased further when it is gate-controlled with an external small-voltage input pulse because charge-carrier mobility in the polysilicon MOS transistors is smaller than that in single-crystal MOS transistors, therefore a time is increased which is required for a voltage to reach a value sufficient to control ON-OFF of a current of the MOS transistor, and as a result the above-explained through current is increased.

The present invention has been made so as to solve the above problems, and it is an object of the present invention to provide a display device having a voltage level converter with the above-explained through current sufficiently suppressed.

The following explains the representative ones of the present inventions briefly.

In accordance with an embodiment of the present invention, there is provided a display device including a pair of substrates, an electrooptical material layer sandwiched between the pair of substrates, a plurality of pixels formed between the pair of substrates and a driver circuit for driving the plurality of pixels provided on one of the pair of substrates, the driver circuit including a level converter circuit comprised of MISTFTs (Metal Insulator Semiconductor Thin Film Transistors) having semiconductor layers made of polysilicon, the level converter circuit comprising: a pair of a first NMISTFT (N-channel type Metal Insulator Semiconductor Thin Film Transistor) and a first PMISTFT (P-channel type Metal Insulator Semiconductor Thin Film Transistor), each of the first NMISTFT and

the first PMISTFT having both a gate terminal thereof and a first terminal thereof coupled to an input terminal for receiving an input pulse via a first capacitance; a pair of a second NMISTFT and a second PMISTFT, each of the second NMISTFT and the second PMISTFT having a  
5 second terminal thereof coupled to the input terminal via a second capacitance; a third PMISTFT having a gate terminal thereof coupled to the gate terminals and the first terminals of the first NMISTFT and the first PMISTFT; a third NMISTFT having a gate terminal thereof coupled to the second terminals of the second NMISTFT and the second  
10 PMISTFT, a first terminal of the third PMISTFT, a second terminal of the first NMISTFT, and a second terminal of the first PMISTFT being coupled to a high-voltage power supply line, a second terminal of the third NMISTFT, a gate terminal and a first terminal of the second NMISTFT, a gate terminal and a first terminal of the second PMISTFT  
15 being coupled to a low-voltage power supply line, and a first junction point between a second terminal of the third PMISTFT and a first terminal of the third NMISTFT being connected to an output terminal of the level converter circuit.

In accordance with another embodiment of the present invention,  
20 there is provided a display device including a pair of substrates, an electrooptical material layer sandwiched between the pair of substrates, a plurality of pixels formed between the pair of substrates and a driver circuit for driving the plurality of pixels provided on one of the pair of substrates, the driver circuit including  
25 a level converter circuit comprised of MISTFTs (Metal Insulator

Semiconductor Thin Film Transistors) having semiconductor layers made of polysilicon, the level converter circuit having a plurality of stages arranged in series, each of the plurality of stages comprising: a pair of a first NMISTFT (N-channel type Metal Insulator Semiconductor Thin Film Transistor) and a first PMISTFT (P-channel type Metal Insulator Semiconductor Thin Film Transistor), each of the first NMISTFT and the first PMISTFT having both a gate terminal thereof and a first terminal thereof coupled to an input terminal for receiving an input pulse via a first capacitance; a pair of a second NMISTFT and a second PMISTFT, each of the second NMISTFT and the second PMISTFT having a second terminal thereof coupled to the input terminal via a second capacitance; a third PMISTFT having a gate terminal thereof coupled to the gate terminals and the first terminals of the first NMISTFT and the first PMISTFT; a third NMISTFT having a gate terminal thereof coupled to the second terminals of the second NMISTFT and the second PMISTFT, a first terminal of the third PMISTFT, a second terminal of the first NMISTFT, and a second terminal of the first PMISTFT being coupled to a high-voltage power supply line, a second terminal of the third NMISTFT, a gate terminal and a first terminal of the second NMISTFT, a gate terminal and a first terminal of the second PMISTFT being coupled to a low-voltage power supply line, and a first junction point between a second terminal of the third PMISTFT and a first terminal of the third NMISTFT being connected to an output terminal.

25 In accordance with another embodiment of the present invention,

there is provided a display device including a pair of substrates, an electrooptical material layer sandwiched between the pair of substrates, a plurality of pixels formed between the pair of substrates and a driver circuit for driving the plurality of pixels

5 provided on one of the pair of substrates, the driver circuit including a level converter circuit comprised of MISTFTs (Metal Insulator Semiconductor Thin Film Transistors) of a same conductivity type and having semiconductor layers made of polysilicon, the level converter circuit comprising a first MISTFT, a second MISTFT, and a third MISTFT,

10 first terminals of the first MISTFT and the second MISTFT being coupled to an input terminal for receiving an input pulse, gate terminals of the first MISTFT and the second MISTFT being coupled to a fixed-voltage power supply line, a second terminal of the first MISTFT being coupled to a gate terminal of the third MISTFT and a first terminal of a

15 capacitor, a second terminal of the third MISTFT being coupled to a high-voltage power supply line, a first terminal of the third MISTFT being coupled to a second terminal of the second MISTFT, and a junction point of the second terminal of the second MISTFT, the first terminal of the third MISTFT, and a second terminal of the capacitor being

20 connected to an output terminal of the level converter circuit.

In accordance with another embodiment of the present invention, there is provided a display device including a pair of substrates, an electrooptical material layer sandwiched between the pair of substrates, a plurality of pixels formed between the pair of

25 substrates and a driver circuit for driving the plurality of pixels

provided on one of the pair of substrates, the driver circuit including a level converter circuit comprised of MISTFTs (Metal Insulator Semiconductor Thin Film Transistors) of a same conductivity type and having semiconductor layers made of polysilicon, the level converter  
5 circuit comprising a first MISTFT, a second MISTFT, and a third MISTFT, first terminals of the first MISTFT and the second MISTFT being coupled to an input terminal for receiving an input pulse, a gate terminal of the first MISTFT being coupled to a fixed-voltage power supply line, a gate terminal of the second MISTFT being supplied with a pulse equal  
10 in magnitude and opposite in phase with respect to the input pulse, a second terminal of the first MISTFT being coupled to a gate terminal of the third MISTFT and a first terminal of a capacitor, a first terminal of the third MISTFT being coupled to a high-voltage power supply line, and a junction point of a second terminal of the second  
15 MISTFT, a second terminal of the third MISTFT, and a second terminal of the capacitor being connected to an output terminal of the level converter circuit.

In accordance with another embodiment of the present invention, there is provided a display device including a pair of substrates,  
20 an electrooptical material layer sandwiched between the pair of substrates, a plurality of pixels formed between the pair of substrates and a driver circuit for driving the plurality of pixels provided on one of the pair of substrates, the driver circuit including a level converter circuit comprised of MISTFTs (Metal Insulator  
25 Semiconductor Thin Film Transistors) of a same conductivity type and



having semiconductor layers made of polysilicon, the level converter circuit having a plurality of stages arranged in series, each of the plurality of stages comprising: a first MISTFT, a second MISTFT, and a third MISTFT, first terminals of the first MISTFT and the second MISTFT being coupled to an input terminal for receiving an input pulse, a gate terminal of the first MISTFT being coupled to a fixed-voltage power supply line, a gate terminal of the second MISTFT being supplied with a pulse equal in magnitude and opposite in phase with respect to the input pulse, a second terminal of the first MISTFT being coupled to a gate terminal of the third MISTFT and a first terminal of a capacitor, a first terminal of the third MISTFT being coupled to a high-voltage power supply line, and a junction point of a second terminal of the second MISTFT, a second terminal of the third MISTFT, and a second terminal of the capacitor being connected to an output terminal.

#### BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings, in which like reference numerals designate similar components throughout the figures, and in which:

FIG. 1A is a circuit diagram of an embodiment of a voltage level converter fabricated in the liquid crystal display device in accordance with the present invention, and FIG. 1B illustrates waveforms of an input pulse and signals at three nodes in the voltage level converter of FIG. 1A;

FIG. 2 is an equivalent circuit diagram of an overall

configuration of an embodiment of the liquid crystal display device in accordance with the present invention;

FIG. 3 is a circuit diagram of another embodiment of a voltage level converter fabricated in the liquid crystal display device in accordance with the present invention;

FIG. 4A is a circuit diagram of another embodiment of a voltage level converter fabricated in the liquid crystal display device in accordance with the present invention, and FIG. 4B illustrates waveforms of an input pulse and signals at four nodes in the voltage level converter of FIG. 4A;

FIG. 5 is a circuit diagram of another embodiment of a voltage level converter fabricated in the liquid crystal display device in accordance with the present invention;

FIG. 6 is a circuit diagram of another embodiment of a voltage level converter fabricated in the liquid crystal display device in accordance with the present invention;

FIG. 7A is a circuit diagram of another embodiment of a voltage level converter fabricated in the liquid crystal display device in accordance with the present invention, and FIG. 7B illustrates waveforms of an input pulse and signals at seven nodes in the voltage level converter of FIG. 7A;

FIGS. 8A to 8D are circuit diagrams of other embodiments of a voltage level converter fabricated in the liquid crystal display device in accordance with the present invention, respectively;

FIGS. 9A to 9C are circuit diagrams of other embodiments of a

voltage level converter fabricated in the liquid crystal display device in accordance with the present invention, respectively;

FIG. 10A is a circuit diagram of another embodiment of a voltage level converter fabricated in the liquid crystal display device in accordance with the present invention, and FIG. 10B illustrates waveforms of an input pulse and signals at two nodes in the voltage level converter of FIG. 10A;

FIG. 11A is a circuit diagram of another embodiment of a voltage level converter fabricated in the liquid crystal display device in accordance with the present invention, FIG. 11B illustrates waveforms of an input pulse and signals at two nodes in the voltage level converter of FIG. 11A, and FIG. 11C is a circuit diagram of a modification of the embodiment of FIG. 11A;

FIG. 12A is a circuit diagram of another embodiment of a voltage level converter fabricated in the liquid crystal display device in accordance with the present invention, and FIG. 12B illustrates waveforms of an input pulse and signals at three nodes in the voltage level converter of FIG. 12A;

FIG. 13A is a circuit diagram of another embodiment of a voltage level converter fabricated in the liquid crystal display device in accordance with the present invention, FIG. 13B illustrates waveforms of an input pulse and signals at four nodes in the voltage level converter of FIG. 13A, FIG. 13C illustrates changes of the potentials at the nodes N1 and N2 of FIG. 13A in greater detail, and FIG. 13D illustrates changes of the potentials at the nodes N3 and N4 of FIG.

13A in greater detail;

FIG. 14A is a circuit diagram of another embodiment of a voltage level converter fabricated in the liquid crystal display device in accordance with the present invention, FIG. 14B illustrates waveforms of an input pulse and signals at four nodes in the voltage level converter of FIG. 14A, FIG. 14C illustrates changes of the potentials at the nodes N1 and N2 of FIG. 14A in greater detail, and FIG. 14D illustrates changes of the potentials at the nodes N3 and N4 of FIG. 14A in greater detail;

FIG. 15A is a circuit diagram of another embodiment of a voltage level converter fabricated in the liquid crystal display device in accordance with the present invention, FIG. 15B illustrates waveforms of an input pulse and signals at four nodes in the voltage level converter of FIG. 15A, FIG. 15C illustrates changes of the potentials at the nodes N1 and N2 of FIG. 15A in greater detail, and FIG. 15D illustrates changes of the potentials at the nodes N3 and N4 of FIG. 15A in greater detail;

FIG. 16 is a circuit diagram of an example of a general conventional voltage level converter; and

FIG. 17 is a circuit diagram of another example of a general conventional voltage level converter.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The embodiments of the display device in accordance with the

present invention will be explained in detail by reference to the drawings.

For the sake of being specific, we shall assume throughout this specification that a liquid crystal material layer is used as an electrooptical material layer in the display device. It is needless to say that an electrooptical material layer other than the liquid crystal material layer, an electroluminescent material layer, for example, can be used instead in the following embodiments.

10           Embodiment 1

          --Overall Configuration--

FIG. 2 is a schematic illustration of an overall configuration of the liquid crystal display device in accordance with the present invention, and is a plan view representing an actual geometrical arrangement of the components of the liquid crystal display device.

FIG. 2 depicts a transparent substrate SUB1 made of glass, for example, which is one of a pair of opposing transparent substrates sandwiching a liquid crystal layer. In a central area (a display area AR) on a liquid-crystal-layer-side surface of the transparent substrate SUB1, excluding its periphery, there are a plurality of gate signal lines GL extending in the x direction and arranged in the y direction and a plurality of drain signal lines DL extending in the y direction and arranged in the x direction.

Each pixel area is formed by an area surrounded by two adjacent gate signal lines GL and two adjacent drain signal lines DL. Each

pixel area is provided with a thin film transistor TFT operated by a scanning signal supplied from one of the two gate signal lines GL and a pixel electrode PX supplied with a video signal from one of the drain signal lines DL via the thin film transistor TFT.

5        Scanning signals (voltage signals) are supplied to the gate signal lines GL sequentially in the order from the top to the bottom in FIG. 2, and the thin film transistors TFT are turned ON by the scanning signals. In synchronism with this, the pixel electrodes PX are supplied with video signals (voltage signals) from the  
10        corresponding drain signal lines DL via the corresponding thin film transistors TFT in the ON state.

Each of the pixel electrodes PX generates an electric field between it and a counter electrode (not shown) for all the pixel areas in common on a liquid-crystal-layer-side  
15        surface of the other transparent substrates opposing the transparent substrate SUB1, for example, so that the electric field control the light transmission through the liquid crystal layer.

Each of the gate signal lines GL is connected at one end  
20        thereof (at the right-hand side of FIG. 2) to a pixel-driving shift register 1, which supplies scanning signals sequentially to the gate signal lines GL. Each of the drain signal lines DL is connected at one end thereof to a D-A converter circuit 2, a memory 3, a data input circuit 4, and a horizontal address  
25        decoder 5 in this order (toward the top side of FIG. 2).

Connected to the memory 3 are a vertical address decoder 6 and a memory-driving shift register 7.

Supplied to the liquid crystal display device of this configuration is information including a start pulse clock  
5 signal, pixel data, horizontal pixel addresses, and vertical pixel addresses. The start pulse clock signal is supplied to the memory-driving shift register 7 and the pixel-driving shift register 1, the horizontal pixel addresses are supplied to the horizontal address decoder 5, the pixel data are supplied to  
10 the data input circuit 4, and the vertical pixel addresses are supplied to the vertical address decoder 6.

In the above circuit configuration, the voltage level converters VLC are employed at positions requiring level conversion of a voltage. In FIG. 2, the voltage level  
15 converters VLC are added in series with the input of the horizontal address decoder 5 for receiving horizontal pixel addresses, in series with the input of the data input circuit 4 for receiving pixel data, between the memory 3 and the D-A converter circuit 2, and between the pixel-driving shift  
20 register 1 and the gate signal lines GL.

In the display area AR and the circuits at its periphery fabricated on the surface of the transparent substrate SUB1, by using a photolithographic technique, laminations of conductive layers, semiconductor layers and insulating  
25 layers selectively etched in specified patterns form thin

film transistors (metal insulator semiconductor thin film transistors, hereinafter MISTFTs), and pixel electrodes, signal lines and others etched in specified patterns are disposed. The semiconductor layers are made of polycrystalline silicon (p-Si), for example.

--Level Converter Circuit--

FIG. 1A is a circuit diagram of an embodiment of the level converter VLC. It is not necessary to employ the level converter VLC at all of the positions indicated in FIG. 2, but the level converters VLC may be employed at positions requiring them or other positions.

In FIG. 1A, an input terminal for receiving an input pulse  $V_{IN}$  is coupled to a gate terminal and a first terminal (one of a source terminal and a drain terminal) of an n-channel type MOS transistor NMOS1 and to a gate terminal and a first terminal (one of a source terminal and a drain terminal) of a p-channel type MOS transistor PMOS1, via a first capacitance C1. Also the input terminal for receiving the input pulse  $V_{IN}$  is coupled to a second terminal (the other of the source terminal and the drain terminal) of an n-channel type MOS transistor NMOS2 and a second terminal (the other of the source terminal and the drain terminal) of a p-channel type MOS transistor PMOS2, via a second capacitance C2.

The gate terminals and the first terminals of both



the n-channel type MOS transistor NMOS1 and the p-channel type MOS transistor PMOS1 are coupled to a gate terminal of the p-channel type MOS transistor PMOS3. The second terminals of both the n-channel type MOS transistor NMOS2 and the p-channel type MOS transistor PMOS2 are coupled to a gate terminal of an n-channel type MOS transistor NMOS3. Second terminals of both the n-channel type MOS transistor NMOS1 and the p-channel type MOS transistor PMOS1, and a first terminal of the p-channel type MOS transistor PMOS3 are coupled to a high-voltage power supply line VDD.

Gate terminals and first terminals of both the n-channel type MOS transistor NMOS2 and the p-channel type MOS transistor PMOS2, and a second terminal of an n-channel type MOS transistor NMOS3 are coupled to a low-voltage power supply line VSS.

Reference characters VDD and VSS will be hereinafter used not only to designate the lines but also to specify the voltages on the lines.

The p-channel type MOS transistor PMOS3 and the n-channel type MOS transistor NMOS3 form a complementary MOS transistor (CMOS), and a junction point between a second terminal of the p-channel type MOS transistor PMOS3 and a first terminal of the n-channel type MOS transistor NMOS3 forms an output terminal.

The following explains the operation of the voltage level converter VLC of the above configuration. FIG. 1B illustrates waveforms of the input pulse  $V_{IN}$  and signals at nodes  $N2$  to  $N4$  indicated in FIG. 1A. The input pulse  $V_{IN}$  is capacitively coupled to the nodes  $N2$  and  $N3$  via capacitances  $C1$  and  $C2$ , respectively, and voltage changes  $\pm \Delta V$  in the input pulse  $V_{IN}$  cause voltage changes  $\pm \Delta V(N2)$  and  $\pm \Delta V(N3)$  at the nodes  $N2$  and  $N3$ , respectively. The voltage changes  $\pm \Delta V(N2)$  and  $\pm \Delta V(N3)$  are approximately represented by the following equations (1) and (2), respectively:

$$\Delta V(N2) = C1 \times \Delta V / (C1 + C1S) \quad (1)$$

$$\Delta V(N3) = C2 \times \Delta V / (C2 + C2S) \quad (2),$$

where  $C1S$  and  $C2S$  are so-called parasitic capacitances formed at the nodes  $N2$  and  $N3$ , respectively, and are equal to the whole capacitances formed at the respective nodes  $N2$ ,  $N3$  minus the regular capacitances  $C1$ ,  $C2$ , respectively.

Hereinafter an n-channel type MOS transistor is represented by an NMOS $b$  with  $b$  being a serial number for identification and a p-channel type MOS transistor is represented by a PMOS $b$  with  $b$  being a serial number for identification.

The subsequent explanation will be made on the basis of the assumptions that circuit parameters are selected to the following equations (3), (4), (5a) and (5b):

$$\Delta V(N2) = V_{th}(NMOS1) + |V_{th}(PMOS1)| + V_{leff} \quad (3)$$

$$\Delta V(N3) = V_{th}(NMOS2) + |V_{th}(PMOS2)| + V_{2eff} \quad (4)$$

$$V_{1eff} > 0 \quad (5a)$$

$$V_{2eff} > 0 \quad (5b),$$

where  $V_{th}(aMOSb)$  represents a threshold voltage of an  $a$  ( $a = p$  or  
5  $n$ )-channel type MOS transistor  $b$  ( $b = a$  serial number for  
identification), and  $V_{ceff}$  is defined as a voltage applied to a gate  
terminal of the MOS transistor and having a value sufficient to turn  
the MOS transistor ON, minus a threshold voltage of the MOS transistor,  
and referred to as an operative voltage with  $c$  being a serial number  
10 for identification.

Assume that the input pulse  $V_{IN}$  is input to a node  $N1$  (see FIG.  
1A), and a power source for the circuit is turned on in time between  
times  $t_0$  and  $t_1$  in FIG. 1B. The node  $N2$  is at a voltage lower by a  
voltage approximately equal to  $|V_{th}(PMOS1)|$  than the high-voltage  
15 power supply voltage  $V_{DD}$ , and the node  $N3$  is at a voltage higher by  
a voltage approximately equal to  $|V_{th}(PMOS2)|$  than the low-voltage  
power supply voltage  $V_{SS}$ . PMOS3 receives the voltage of the node  $N2$   
as its gate voltage and NMOS3 receives the voltage of the node  $N3$  as  
its gate voltage. At this time there is possibility that both PMOS3  
20 and NMOS3 connected in series will be in their weakly conducting (ON)  
states, and consequently, there is a danger that a through current  
flows from the high-voltage power supply line  $V_{DD}$  to the low-voltage  
power supply line  $V_{SS}$  through PMOS3 and NMOS3, and instability is  
caused in a signal voltage at a node  $N4$  depending upon the amount of  
25 the through current. This problem can be solved by varying a voltage

of the input pulse  $V_{IN}$  at the instant of the power turn-on or immediately after the instant of the power turn-on so as to turn one of PMOS3 and NMOS3 off.

When the input pulse  $V_{IN}$  changes by  $+\Delta V$  from a low level (hereinafter referred to as "L") to a high level (hereinafter referred to as "H"), the voltages at the nodes N2 and N3 rise by  $\Delta V(N2)$  and  $\Delta V(N3)$  due to capacitive coupling by capacitances  $C1$  and  $C2$ , respectively.

In this case, the voltage  $V(N2)$  at the node N2 is obtained by using the above equation (3) as shown below.

$$\begin{aligned} V(N2) &= VDD + \Delta V(N2) - |V_{th}(PMOS1)| \\ &= VDD + V_{th}(NMOS1) + V_{leff} \end{aligned} \quad (6)$$

This indicates that PMOS3 is driven into its highly non-conducting (OFF) state.

The voltage  $V(N3)$  at the node N3 is obtained by using the above equation (4) as shown below.

$$\begin{aligned} V(N3) &= VSS + \Delta V(N3) + |V_{th}(PMOS2)| \\ &= VSS + V_{th}(NMOS2) + 2|V_{th}(PMOS2)| + V_{2eff} \end{aligned} \quad (7)$$

This indicates that NMOS3 is in its ON state.

As a result, when the voltage of the input pulse  $V_{IN}$  changes by  $+\Delta V$ , the OFF state of PMOS3 and the ON state of NMOS3 are caused approximately simultaneously.

During time from  $t1$  to  $t2$ ,  $V(N2) = VDD + V_{th}(NMOS1) + V_{leff}$ , therefore NMOS is turned ON and  $V(N2)$  is decreasing, and NMOS1 is cut off when  $V(N2)$  is near a voltage equal to  $VDD + V_{th}(NMOS1)$ . At this

time the gate voltage of PMOS3 is  $V(N2)$  which is  $VDD + V_{th}(NMOS1)$ , and the source voltage is at the voltage of  $VDD$ , and therefore PMOS is maintained in the OFF state.

Similarly, since  $V(N3) = VSS + V_{th}(NMOS2) + 2|V_{th}(PMOS2)| + V_{2eff}$ ,  
5 PMOS2 is turned ON, and  $V(N3)$  is decreasing, but PMOS2 is cut off when  $V(N3)$  is near a voltage equal to  $VSS + |V_{th}(PMOS2)|$ .

In this case, if  $|V_{th}(PMOS2)| \geq V_{th}(NMOS3)$ , NMOS3 maintains its ON state, but if  $|V_{th}(PMOS2)| < V_{th}(NMOS3)$ , NMOS3 is cut off and goes into an OFF state.

10 Here the case in which  $|V_{th}(PMOS2)| \geq V_{th}(NMOS3)$  will be discussed. Since PMOS3 maintains its OFF state, if NMOS3 can discharge an electric charge  $C(N4) \times (V_{INT} - VSS)$  stored at the node N4 into the line  $VSS$ , the voltage  $V(N4)$  at the node N4 can be made equal to the voltage of the line  $VSS$ .  $C(N4)$  represents a capacitance  
15 formed at the node 4, and  $V_{INT}$  represents a voltage of the node N4 at time  $t1$ .

A current provided when the gate voltage  $V(N2)$  of NMOS3 becomes equal to  $VSS + |V_{th}(PMOS2)|$  shall be represented by the following notation (8):

20 
$$I(NMOS3, V_{th}(PMOS2)) \quad (8)$$

The voltage  $V(N4)$  at the node N4 is made equal to  $VSS$  if the circuit parameters are selected so as to satisfy at least the following inequality (9):

$$I(NMOS3, V_{th}(PMOS2)) \times (t2 - t1) \geq C(N4) \times (V_{INT} - VSS) \quad (9)$$

25 And if the following inequality (10) is satisfied:

$$|V_{th}(PMOS2)| < V_{th}(NMOS3) \quad (10),$$

NMOS3 is cut off when  $V(N2)$  becomes equal to  $V_{th}(NMOS3)$ .

Let  $t_{eff1}$  be time required for NMOS3 to be cutoff from time  $t1$ . PMOS3 is in the OFF state, and therefore  
 5 the charge  $Q'(1)$  discharged by NMOS3 is given by the following equation (11) integrating  $I(t)$  between times  $t1$  and  $(t1 + t_{eff1})$ :

$$Q'(1) = \int I(t)dt \quad (11)$$

where

10 let  $\beta$  = a current conversion factor in NMOS3,

$Q(t)$  = the amount of charge at the node N4 at time  $t$ ,

$C(N4)$  = a capacitance formed at the node N4, then

(a) if  $Q(t)/C(N4) < V(N3)(t) - V_{th}(NMOS2)$ ,

15  $I(t) = \beta((V(N3)(t) - V_{th}(NMOS2))(Q(t)/C(N4)) - (Q(t)/C(N4)) \times (Q(t)/C(N4))/2$ , and

(b) if  $Q(t)/C(N4) \geq (V(N3)(t) - V_{th}(NMOS2))$ ,

$$I(t) = \beta(V(N3)(t) - V_{th}(NMOS2)) \times (V(N3)(t) - V_{th}(NMOS2))/2.$$

If  $Q'(1) = Q(t = t1)$ , the voltage  $V(N4)$  at the node 4 becomes  
 20 equal to the low-voltage power supply voltage VSS. Conversely speaking, by letting  $Q'(1)$  in the above equation (11) =  $Q(t = t1)$ , an integrating time  $t_x$  is obtained from the equation (11), and if the integrating time  $t_x$  satisfies the inequality  $t_x \leq t_{eff1}$ , the voltage  $V(N4)$  at the node N4 can be made equal to VSS.

25 When the input pulse  $V_{IN}$  changes by  $-\Delta V$  from "H" to "L" at time

t<sub>2</sub>, the voltages at the nodes N2 and N3 fall by  $\Delta V(N2)$  and  $\Delta V(N3)$  from the corresponding voltages immediately prior to time 2 by capacitive couplings of capacitances C1 and C2, respectively, as described above. Here, the voltage V(N3) at the node N3 is represented  
5 by the following equation (12) obtained by using the above equation (4) and others:

$$\begin{aligned} V(N3) &= VSS + |V_{th}(PMOS2)| - \Delta V(N3) \\ &= VSS - V_{th}(NMOS2) - V_{2eff} \end{aligned} \quad (12)$$

As a result, the voltage V(N3) at the node N3, that is, the gate  
10 voltage of NMOS3 becomes lower by  $V_{th}(NMOS2) + V_{1eff}$  than the source voltage VSS of NMOS3, and thereby NMOS3 is brought into the OFF state.

The voltage V(N2) at the node N2 is represented by the following equation (13) obtained by using the above equation (3) and others:

$$\begin{aligned} V(N2) &= VDD + |V_{th}(NMOS1)| - \Delta V(N2) \\ 15 \quad &= VDD - |V_{th}(PMOS1)| - V_{1eff} \end{aligned} \quad (13)$$

As a result, the voltage V(N2) at the node N2, that is, the gate voltage of PMOS3 becomes lower by  $|V_{th}(PMOS1)| + V_{1eff}$  than the source voltage VDD of PMOS3, and thereby PMOS3 is brought into the ON state.

During time from t<sub>2</sub> to t<sub>3</sub>, if  $V_{th}(NMOS2) \geq |V_{th}(PMOS2)| + V_{1eff}$ ,  
20 NMOS2 is brought into the ON state, the voltage V(N3) at the node N3 continues to rise, but NMOS2 is cut off when it becomes near the voltage  $VSS - |V_{th}(PMOS1)|$ , and thereby NMOS3 maintains the OFF state.

At time t<sub>2</sub>, as is apparent from the above equation (6), the gate voltage V(N2) of PMOS1 is lower by  $|V_{th}(PMOS1)| + V_{1eff}$  than the  
25 source voltage VDD of PMOS1, PMOS is brought into the ON state, and

the voltage  $V(N2)$  at the node N2 becomes higher, but PMOS1 is cut off and is brought into the OFF state when the voltage  $V(N2)$  becomes near  $|V_{th}(PMOS1)|$ .

As a result, if the following inequality (14) is satisfied:

$$5 \quad |V_{th}(PMOS1)| \geq |V_{th}(PMOS3)| \quad (14),$$

PMOS3 maintains the ON state.

Since NMOS3 maintains the OFF state, if PMOS3 can discharge a charge  $C(N4) \times (VDD - VSS)$  stored at the node 4 toward the high-voltage power supply line VDD, the voltage  $V(N4)$  at the node N4 can  
10 be made equal to VDD.

A current through PMOS3 when the gate voltage  $V(N2)$  of PMOS3 becomes equal to  $VDD - |V_{th}(PMOS1)|$  shall be represented by the following notation (15):

$$I(PMOS3, V_{th}(PMOS1)) \quad (15)$$

15 The voltage  $V(N4)$  at the node N4 is made equal to VDD if the circuit parameters are selected so as to satisfy at least the following inequality (16):

$$I(PMOS3, V_{th}(PMOS1)) \times (t_3 - t_2) \geq C(N4) \times (VDD - VSS) \quad (16).$$

And if  $|V_{th}(PMOS1)| < |V_{th}(PMOS3)|$ , PMOS3 is cut off.

20 Let  $t_{eff2}$  be time required for PMOS3 to be cutoff from time  $t_2$ . NMOS3 is in the OFF state, and therefore the charge  $Q'(2)$  discharged by PMOS3 is given by the following equation (17) integrating  $I(t)$  between times  $t_2$  and  $(t_2 + t_{eff2})$ :

$$25 \quad Q'(2) = \int I(t) dt \quad (17)$$



where

let  $\beta_P$  = a current conversion factor in PMOS3,

$Q(t)$  = the amount of charge at the node N4 at time  $t$ ,

5  $C(N4)$  = a capacitance formed at the node N4, and

(a) if  $Q(t)/C(N4) < V(N3)(t) - |V_{th}(PMOS1)|$ , the current flowing through PMOS3,  $I(t) = \beta_P \{ (V(N3)(t) - |V_{th}(PMOS1)|)(Q(t)/C(N4)) - (Q(t)/C(N4)) \times (Q(t)/C(N4))/2 \}$ , and

(b) if  $Q(t)/C(N4) \geq (V(N3)(t) - |V_{th}(PMOS1)|)$ , the current flowing  
10 through PMOS3,  $I(t) = \beta_P (V(N3)(t) - V_{th}(NMOS2)) \times (V(N3)(t) - V_{th}(NMOS2))/2$ .

If  $Q'(2) = Q(t = t_2)$ , the voltage  $V(N4)$  at the node 4 becomes equal to the low-voltage power supply voltage VSS. Conversely speaking, by letting  $Q'(2)$  in the above equation (17) =  $Q(t = t_2)$ ,  
15 an integrating time  $t_x$  is obtained from the equation (17), and if the integrating time  $t_x$  satisfies the inequality  $t_x \leq t_{eff2}$ , the voltage  $V(N4)$  at the node N4 can be made equal to VSS.

When the input pulse  $V_{IN}$  changes by  $+\Delta V$  from "L" to "H" again at time  $t_3$ , the voltages at the nodes N2 and N3 rise by  $\Delta V(N2)$  and  
20  $\Delta V(N3)$  from the corresponding voltages immediately prior to time 3 by capacitive couplings of capacitances  $C1$  and  $C2$ , respectively, as described above. Here, the voltage  $V(N2)$  at the node N2 is represented by the following equation (18) obtained by using the above equation (3) and others:

25 
$$V(N2) = V_{DD} - |V_{th}(PMOS1)| + \Delta V(N2)$$

$$= VDD + V_{th}(NMOS1) + V_{leff} \quad (18)$$

As a result, PMOS3 is brought into the strongly OFF state, and the voltage  $V(N3)$  at the node N3 is represented by the following equation (19) obtained by using the above equation (4) and others:

$$\begin{aligned} V(N3) &= VSS - |V_{th}(PMOS2)| + \Delta V(N3) \\ &= VSS + V_{th}(NMOS2) + V_{2eff} \end{aligned} \quad (19)$$

Thereby NMOS3 is brought into the ON state.

During time from  $t3$  to  $t4$ , since  $V(N2) = VDD + V_{th}(NMOS1) + V_{leff}$ , NMOS1 is brought into the ON state, and  $V(N2)$  decreases, but NMOS1 is cut off when  $V(N2)$  becomes near a voltage  $VDD + V_{th}(NMOS1)$ . At this time, the gate voltage of PMOS3,  $V(N2)$  is  $VDD + V_{th}(NMOS1)$ , and the source voltage of PMOS3 is  $VDD$ , and therefore PMOS3 maintains the OFF state.

Similarly, if  $|V_{th}(PMOS2)| \leq V_{th}(NMOS2) + V_{2eff}$ , PMOS2 is brought into the ON state, the voltage  $V(N3)$  at the node N3 decreases, but PMOS2 is cut off when the voltage  $V(N3)$  becomes near the voltage  $VSS + |V_{th}(PMOS2)|$ .

At this time, if  $|V_{th}(PMOS2)| \geq V_{th}(NMOS3)$ , NMOS3 maintains the ON state, but if  $|V_{th}(PMOS2)| < V_{th}(NMOS3)$ , NMOS3 is cut off and brought into the OFF state when  $V(N3)$  decreases to  $VSS + V_{th}(NMOS3)$ .

Here the relationship between  $|V_{th}(PMOS2)|$  and  $V_{th}(NMOS3)$  is the same as that explained in connection with the operation during the time between times  $t1$  and  $t2$ .

The sequence of operations described above is repeated such that the input pulses  $V_{IN}$  are voltage-level-converted into pulses

V(N4) of waveforms having an amplitude (VDD - VSS) as illustrated in FIG. 1B.

A plurality of the circuits of the configuration of FIG. 1A can be cascaded as desired depending upon the application and other  
5 practical considerations.

#### Embodiment 2

FIG. 3 is a circuit diagram of another embodiment of a voltage level converter VLC fabricated in the liquid crystal display device  
10 in accordance with the present invention. The configuration of FIG. 3 is similar to that of FIG. 1A, except that a capacitance CL is connected between the output terminal and the low-voltage power supply line VSS. The operation of this configuration is approximately the same in performance as that of FIG. 1A.

15 Here, in the operation of the circuit of FIG. 1A, for simplicity, VINT is replaced with VDD in the inequality (9). The inequality (9) is assumed to be a condition for making V(N4) equal to VSS, and the inequality (16) is assumed to be a condition for making V(N4) equal to VDD.

20 First, the following inequalities (20) and (21) are obtained from the inequalities (9) and (16), respectively:

$$I(\text{NMOS3}, V_{th}(\text{PMOS2})) \times (t_2 - t_1) \geq \{C(\text{N4}) + CL\} \times (VDD - VSS) \\ (20),$$

$$I(\text{PMOS3}, V_{th}(\text{PMOS1})) \times (t_3 - t_2) \geq \{C(\text{N4}) + CL\} \times (VDD - VSS) \\ 25 \quad (21).$$

Solving these inequalities (20) and (21) for the load capacitance  $CL$  yields the following inequalities (22) and (23):

$$CL \leq \{I(NMOS3, V_{th}(PMOS2)) \times (t_2 - t_1)\} / (VDD - VSS) - C(N4) \quad (22)$$

$$5 \quad CL \leq \{I(PMOS3, V_{th}(PMOS1)) \times (t_3 - t_2)\} / (VDD - VSS) - C(N4) \quad (23)$$

Solving the inequalities (20) and (21) for the times yields the following inequalities (24) and (25):

$$10 \quad (t_2 - t_1) \geq \{C(N4) + CL\} \times (VDD - VSS) / I(NMOS3, V_{th}(PMOS2)) \quad (24)$$

$$(t_3 - t_2) \geq \{C(N4) + CL\} \times (VDD - VSS) / I(PMOS3, V_{th}(PMOS1)) \quad (25)$$

Solving the inequalities (20) and (21) for the currents yields the following inequalities (26) and (27):

$$15 \quad I(NMOS3, V_{th}(PMOS2)) \geq \{C(N4) + CL\} \times (VDD - VSS) / (t_2 - t_1) \quad (26)$$

$$I(PMOS3, V_{th}(PMOS1)) \geq \{C(N4) + CL\} \times (VDD - VSS) / (t_3 - t_2) \quad (27)$$

Here, when the right side in each of the above inequalities (20) to (27) is assumed to be fixed values, the inequalities (22) and (23) limit the load capacitance, the inequalities (24) and (25) limit the maximum frequency, and the inequalities (26) and (27) limit the currents in the MOS transistors, that is, the dimensions of their gates.

25 This means that it is necessary to select or verify the

circuit parameters of the voltage level converter circuit of this embodiment individually depending upon its load (a load capacitance).

FIG. 4A is a circuit diagram of another embodiment of the voltage level converter VLC in accordance with the present invention modified in view of the above requirement, and FIG. 4B illustrates pulse waveforms of an input pulse and signals at four nodes in the voltage level converter of FIG. 4A.

FIG. 4A is a circuit diagram similar to that of FIG. 3, except that a CMOS inverter is added whose input terminal is coupled to the node N4 and whose output terminal, a node N5, is coupled to the load capacitance CL. There are provided a p-channel type MOS transistor PMOS4 with its first terminal coupled to the high-voltage power supply line VDD and an n-channel type MOS transistor NMOS4 with its second terminal coupled to the low-voltage power supply line VSS.

The gate terminals of the p-channel type MOS transistor PMOS4 and the n-channel type MOS transistor NMOS4 are coupled to the junction point of a second terminal of the p-channel type MOS transistor PMOS3 and a first terminal of the n-channel type MOS transistor NMOS4. The junction point of a second terminal of the p-channel type MOS transistor PMOS4 and a first terminal of the n-channel type MOS transistor NMOS4 forms the output

terminal, and the capacitance  $C_L$  is coupled between the output terminal and the low-voltage power supply line  $V_{SS}$ .

In the operation of this circuit, changes in voltages  $V_{IN}$ ,  $V(N2)$ ,  $V(N3)$  and  $V(N4)$  with time are the same as those explained in connection with Embodiment 1. The voltage  $V(N4)$  is supplied to the CMOS inverter composed of PMOS4 and NMOS4 as its input pulse, the voltage  $V(N5)$  at the node N5 changes with time as shown in FIG. 4B, and the pulse voltages charge the load capacitance  $C_L$ . Here discharging load capacitance in this circuit are limited to parasitic capacitances such as a gate capacitance of the CMOS inverter composed of PMOS4 and NMOS4 and a wiring capacitance  $C_4$  at the node N4. In general, the parasitic capacitances can be made smaller than the load capacitance  $C_L$ , and therefore design parameters of the circuit components can be made realistic values. Furthermore, the voltage level converter of this embodiment of the same circuit parameters an advantage of wider application compared with Embodiment 1, for example.

### 20           Embodiment 3

FIG. 5 is a circuit diagram of another embodiment of the voltage level converter VLC in accordance with the present invention, and is similar to that of FIG. 3.

The circuit diagram of FIG. 5 differs from that of FIG. 4A in that another stage of the CMOS is added which

is composed of a p-channel type MOS transistor PMOS5 and an n-channel type MOS transistor NMOS5, and the load capacitance CL is coupled between its output terminal and the low-voltage power supply line VSS. In FIG. 5, reference character C5 denotes a parasitic capacitance such as a wiring capacitance at the node N5, and a node N6 forms the output terminal. The voltage level converter of this configuration is advantageous in the case of a large load capacitance.

It is needless to say that, to enhance the beneficial effects of this embodiment further, still another stage of the CMOS may be added which is composed of a p-channel type MOS transistor PMOS6 and an n-channel type MOS transistor NMOS6, and the load capacitance CL is coupled between its output terminal and the low-voltage power supply line VSS as shown in FIG. 6. In FIG. 6, reference character C6 denotes a parasitic capacitance such as a wiring capacitance at the node N6, and a node N7 forms the output terminal.

#### Embodiment 4

FIG. 7A is a circuit diagram of another embodiment of the voltage level converter fabricated on a surface of one of two substrate of the liquid crystal display device in accordance with the present invention.

In FIG. 7A, the voltage level converter is composed of a plurality (two in this embodiment) of stages comprising the above-described voltage level converters VLC coupled in cascade. Specifically, a first stage is  
5 formed of the circuit configuration shown in FIG. 1A, a second stage succeeding the first stage is formed of the circuit configuration shown in FIG. 4A, and a CMOS composed of PMOS4 and NMOS4 interposed therebetween couples the first and second stages. A node N9 forms an output  
10 terminal of the voltage level converter of this embodiment.

FIG. 7B illustrates waveforms of the input pulse VIN and voltages V(N2) to V(N8) at the nodes N2 to N8 in the voltage level converter of FIG. 7A. In the operation  
15 of the above-described circuit, waveforms of the voltages VIN, V(N2), V(N3), V(N4) and V(N5) are the same as those explained in connection with Embodiment 2.

In FIG. 7A, reference characters C11, C12, C11S and C12S denote capacitances corresponding to the  
20 capacitances C1, C2, C1S and C2S, respectively, and reference character C8 denotes a parasitic capacitance formed at the node N8.

The voltages V(N6) and V(N7) at the nodes N6 and N7, respectively, vary with time in response to the voltage  
25 V(N5) at the node N5 in the same way as the voltages V(N2)



5            $V_{IN} \ll V_{DD}$                          (28), and also the following  
equations (29) and (30) are satisfied:

$$V(N5)_{\min} = V_{SS} \quad (30)$$

In this embodiment, at a time when the voltages  $V(N6)$  and  $V(N7)$  exceed the threshold voltages of PMOS13 and NMOS13, respectively, the pair of transistors are completely switched between ON and OFF, and consequently, the pulse signals can be transferred to the succeeding stage with less delay time than in the case of usual CMOS inverters.

Embodiment 5

In each of all the above-described embodiments, a series combination of the capacitance C1 and the n-channel type MOS transistor NMOS1 is coupled between the input terminal for receiving the input pulse VIN and the high-voltage power supply line VDD, and the n-channel type MOS transistor NMOS1 functions as a diode.

Therefore, take the circuit configuration of FIG. 1A, for example, the n-channel type MOS transistor NMOS1 can be replaced by a diode D1 with its cathode coupled to the high-voltage power supply line VDD as shown in FIG. 8A.

In each of all the above-described embodiments, a series combination of the capacitance C2 and the n-channel type MOS transistor NMOS2 is coupled between the input terminal for receiving the input pulse VIN and the low-voltage power supply line VSS, and the n-channel type MOS transistor NMOS2 functions as a diode.

Therefore, take the circuit configuration of FIG. 1A, for example, the n-channel type MOS transistor NMOS2 can be replaced by a diode D2 with its anode coupled to the low-voltage power supply line VSS as shown in FIG. 8B.

Furthermore, needless to say, take the circuit configuration of FIG. 1A, for example, the n-channel type

MOS transistors NMOS1 and NMOS2 can be replaced by the diode D1 with its cathode coupled to the high-voltage power supply line VDD and the diode D2 with its anode coupled to the low-voltage power supply line VSS, respectively, as shown in FIG. 8C.

Furthermore, in the above embodiment, the p-channel type MOS transistors PMOS1 and PMOS2 can be replaced by a series combination of a resistance R1 and a diode D3, and a series combination of a resistance R2 and a diode D4, respectively, as shown in FIG. 8D. Needless to say, in this case, only one of the p-channel type MOS transistors PMOS1 and PMOS2 can be replaced by a series combination of a resistance R1 and a diode D3.

Furthermore, in the circuit configuration of FIG. 1A, for example, the gate terminals of NMOS2 and PMOS2 are coupled to the low-voltage power supply line VSS. However, as shown in FIG. 9A, the gate terminals of NMOS2 and PMOS2 may be coupled to the other corresponding terminals of NMOS2 and PMOS2 other than the terminals of NMOS2 and PMOS2 coupled to the low-voltage power supply line VSS.

Furthermore, in the circuit configuration of FIG. 1A, for example, the gate terminals of NMOS1 and PMOS1 are coupled to the corresponding terminals of NMOS1 and PMOS1 other than the terminals of NMOS1 and PMOS1 coupled

to the high-voltage power supply line VDD. However, as shown in FIG. 9B, the gate terminals of NMOS1 and PMOS1 may be coupled to the high-voltage power supply line VDD.

Needless to say, both of the two above features  
5 explained in connection with FIGS. 9A and 9B can be employed as shown in FIG. 9C.

#### Embodiment 6

FIG. 10A is a circuit diagram of another embodiment  
10 of the voltage level converter VLC fabricated on a substrate of the liquid crystal display device in accordance with the present invention.

In FIG. 10A, the input terminal for receiving the input pulse VIN is coupled to first terminals of n-channel  
15 type MOS transistors NMOS1 and NMOS2, gate terminals of the n-channel type MOS transistors NMOS1 and NMOS2 are supplied with a fixed bias voltage VBIAS. A second terminal of the n-channel type MOS transistor NMOS1 is coupled to a gate terminal of an n-channel type MOS  
20 transistor NMOS3 and a first terminal of a capacitance CB. A second terminal of the n-channel type MOS transistor NMOS3 is coupled to the high-voltage power supply line VDD, and a first terminal of the transistor NMOS3 is coupled to a second terminal of the n-channel  
25 type MOS transistor NMOS2. A junction point between the

second terminal of the n-channel type MOS transistor NMOS2 and the first terminal of the n-channel type MOS transistor NMOS3 is coupled to a second terminal of the capacitance CB, and forms an output terminal (a node N2).

5           In FIG. 10A, a series combination of a load resistance RL and a load capacitance CL serving as a resistance-capacitance load is coupled between the output terminal (the node N2) and ground. A capacitance CS indicated by broken lines in FIG. 10A denotes parasitic  
10 capacitances such as a gate capacitance of NMOS3, a source capacitance of NMOS1 and a wiring capacitance formed at the node N1, excluding the capacitance CB.

FIG. 10B is a time chart illustrating waveforms of the input pulse VIN, and signal pulses at two nodes in the voltage level  
15 converter of FIG. 10A, with the abscissa representing time.

Here, let VH and VL be maximum and minimum values of the input pulse VIN, respectively. VH is assumed to be half the maximum power supply voltage VDD, as represented by the following equation (31), and VL is assumed to be ground level (GND) for simplicity.

20           
$$V_H = V_{DD}/2 \quad (31)$$

The bias voltage VBIAS is assumed to be equal to VH, and is represented by the following equation (32):

$$V_{BIAS} = V_H = V_{DD}/2 \quad (32)$$

Let Vth be a threshold voltage, and it is assumed that threshold  
25 voltages of all the n-channel type MOS transistors NMOS1, NMOS2 and

NMOS3 are equal, and the following equation (33) is satisfied:

$$V_{th} = V_H/3 = V_{DD}/6 \quad (33)$$

If the level of the input pulse  $V_{IN}$  changes from the low level (hereinafter referred to as "L") to the high level (hereinafter referred to as "H") at time  $t_1$ , a voltage  $V_{N1}$  at the node N1 rises  
5 to a value represented by the following equation (34) through NMOS1.

$$V_{N1} = V_H - V_{th} \quad (34)$$

Simultaneously with this change, NMOS3 is also brought into the ON state, and a voltage  $V_{N2}$  at the node N2 also begins to rise  
10 toward the voltage represented by the equation (34). At this time, the voltage  $V_{N2}$  at the node N2 rises more slowly than the voltage  $V_{N1}$  at the node N1 because the node N2 is coupled to a load circuit comprised of the load resistance  $R_L$ , the node N3 and the load capacitance  $C_L$ .

Let  $V_{N20}$  be a voltage at the node N2 at the time when the voltage  
15  $V_{N1}$  at the node N1 becomes  $(V_H - V_{th})$  and thereby NMOS1 is cut off, and the following equation (35) is assumed to be satisfied:

$$V_{N1} - V_{N20} = V_H - V_{th} - V_{N20} = V_{th} + \alpha \quad (35)$$

At this time, NMOS3 is brought into the ON state because its gate voltage is  $V_{N1}$ , its drain voltage is  $V_{DD}$ , and its source voltage  
20 is  $V_{N20}$ . Currents from both NMOS2 and NMOS3 continue to flow into the node N2 such that the voltage  $V_{N2}$  at the node N2 is raised, until the voltage  $V_{N2}$  at the node N2 becomes  $(V_H - V_{th})$ , and at the time the voltage  $V_{N2}$  becomes  $(V_H - V_{th})$ , NMOS2 is cut off and the current ceases to flow through it.

25 However, at this time, the voltage  $V_{N1}$  rises as the voltage  $V_{N2}$

at the node N2 rises, because the node N1 has already been made floating due to cutoff of NMOS1, and is capacitively coupled to the node 2 via the capacitance CB.

The voltage VN11 at the node N1 at the time when the voltage  
5 VN2 at the node N2 becomes  $(V_H - V_{th})$  is approximately represented by the following equation (36):

$$VN11 = V_H - V_{th} + (V_{th} + \alpha) \times CB / (CB + CS) \quad (36)$$

Here, if the following equation (37) is satisfied, NMOS3 maintains the ON state.

10 
$$VN11 - (V_H - V_{th}) = (V_{th} + \alpha) \times CB / (CB + CS)$$
  
$$= V_{th} + \beta \quad (37)$$

where  $\beta > 0$

Consequently, the current from the high-voltage power supply line VDD continues to flow into the node N2  
15 through NMOS3, and thereby the voltage VN2 at the node N2 continues to rise.

Let  $\Delta V$  be an increase in the voltage VN2 after the voltage VN2 has become  $(V_H - V_{th})$ . Then, the voltage VN1  
 $\Delta$  at the node N1 at this time is expressed by the following  
20 equation (38):

$$\begin{aligned} VN1\Delta &= VN11 + \Delta V \times CB / (CB + CS) \\ &= V_H - V_{th} + (V_{th} + \alpha + \Delta V) \times CB / (CB + CS) \end{aligned} \quad (38)$$

The value of  $(VN1\Delta - VN2)$  is obtained by subtracting the voltage VN2 at the node N2 represented  
25 by  $(V_H - V_{th} + \Delta V)$  from the voltage VN1 $\Delta$  expressed by the

equation (38), and as far as the following equation (39) is satisfied, NMOS3 maintains the ON state.

$$VN1\Delta - VN2 = (V_{th} + \alpha + \Delta V) \times CB / (CB + CS) - \Delta V > V_{th} \quad (39)$$

5        If the following relationship (41) obtained by substituting the following equation (40) in the equation (39) is satisfied, the voltage VN2 at the node N2 rises up to the voltage VDD.

$$\Delta V = VDD - (VH - V_{th}) \quad (40)$$

10         $(V_{th} + \alpha + VDD - (VH - V_{th})) \times CB / (CB + CS) - (VDD - (VH - V_{th})) > V_{th} \quad (41)$

What is essential in the circuit of this embodiment is that the voltage rise at the node N2 is slower than that at the node N1, and in other words it is necessary  
15 to select circuit parameters so as to ensure this operation, in particular, dimensions of the transistors and the coupling capacitances CB.

In the above explanation, the threshold voltages  $V_{th}$  were assumed to be constant at all times, but for  
20 example, in a case in which it is not permissible to neglect variations in threshold voltages with variations in the respective voltages due to the substrate effect and others, it is necessary to use actual threshold voltages  $V_{th}$ .

If the voltage level of the input pulse VIN changes  
25 from "H" to "L" at time  $t_2$ , the voltage of the input pulse



VIN serves as the source voltages of NMOS1 and NMOS2, and thereby both the transistors NMOS1 and NMOS2 are turned ON since the gate voltages of both the transistors NMOS1 and NMOS2 are VBIAS at this time, and consequently, the  
5 charge stored at the node N1 is discharged toward the input terminal for the input pulse VIN through NMOS1.

As is apparent from the previous explanation, discharging of the charge stored at the node N1 is fast, by this discharging NMOS3 is turned OFF, and as a result  
10 supply of charge (current) from the high-voltage power supply line VDD is ceased.

The charges stored at the nodes N2 and N3 are discharged toward the input terminal for the input pulse VIN through NMOS2, the voltages VN1, VN2 and VN3 at the  
15 nodes N1, N2 and N3, respectively, become VL (= GND). The sequence of operations described above is repeated.

#### Embodiment 7

FIG. 11A is a circuit diagram of another embodiment  
20 of the voltage level converter VLC fabricated on a surface of a substrate of the liquid crystal display device in accordance with the present invention, and is similar to that of FIG. 10A.

The configuration of FIG. 11A differs from that of FIG. 10A  
25 in that the gate terminal of the n-channel type MOS transistor NMOS2

is supplied with a pulse  $V_{INinvert}$  equal in magnitude and opposite in phase with respect to the input pulse  $V_{IN}$  instead of the fixed voltage  $V_{BIAS}$ . In this specification, the suffix "invert" is also used instead of the bar ( $\bar{\phantom{x}}$ ) to indicate an inversion.

5       The following explains operation of the circuit of FIG. 11A by reference to FIG. 11B.

At time  $t_1$ , the input pulse  $V_{IN}$  changes from "L" to "H", the voltage  $V_{N1}$  at the node  $N1$  rises up to the value expressed by the following equation (42) via NMOS1.

10       
$$V_{N1} = V_H - V_{th} \quad (42)$$

At this time, since the gate of NMOS2 is supplied with the voltage  $V_{INinvert}$  opposite in phase with respect to the input pulse  $V_{IN}$ , NMOS2 is turned OFF, and therefore a rise in the voltage  $V_{N2}$  at the node  $N2$  via NMOS2 does  
15 not occur.

If the following equation (43) is satisfied, NMOS3 is turned ON, and thereby the voltage  $V_{N2}$  at the node  $N2$  begins to rise.

$$V_{N1} = V_H - V_{th} \quad (43)$$

20       For simplicity, the voltage rise at the node  $N2$  is neglected which has been caused through NMOS3 before the voltage  $V_{N1}$  at the node  $N1$  reaches the value expressed by the equation (43). Let  $\Delta V$  be a voltage rise in the voltage  $V_{N2}$  after this time, and then the voltage  $V_{N1}$   
25  $\Delta$  at the node  $N1$  is expressed by the following equation

(44).

$$\begin{aligned} VN1\Delta &= VN1 + \Delta V \times CB / (CB + CS) \\ &= VH - v_{th} + \Delta V \times CB / (CB + CS) \end{aligned} \quad (44)$$

The value of  $(VN1\Delta - VN2)$  is obtained by subtracting  
5 the voltage  $VN2$  at the node  $N2$  represented by  $\Delta V$  from  
the voltage  $VN1\Delta$  expressed by the equation (44), and as  
far as the following equation (45) is satisfied, NMOS3  
maintains the ON state.

$$VN1\Delta - VN2 = VH - v_{th} + \Delta V \times CB / (CB + CS) - \Delta V > v_{th} \quad (45)$$

If the following relationship (47) obtained by  
substituting the following equation (46) in the equation  
(45) is satisfied, the voltage  $VN2$  at the node  $N2$  rises  
up to the voltage  $VDD$  on the high-voltage power supply  
15 line  $VDD$ .

$$\Delta V = VDD \quad (46)$$

$$VH - v_{th} + VDD \times CB / (CB + CS) - VDD > v_{th} \quad (47)$$

The subsequent operation is the same as that  
explained in connection with Embodiment 6, and therefore  
20 the voltage-level-converted pulses are obtained in this  
embodiment as shown in FIG. 11B.

As a modification of this embodiment, the first terminal of NMOS2  
having  $VIN_{invert}$  applied to its gate electrode can be connected to  
the low-voltage power supply line  $VSS$  as shown in FIG. 11C.

Embodiment 8

FIG. 12A is a circuit diagram of another embodiment of the voltage level converter VLC fabricated on a surface of a substrate of the liquid crystal display device in accordance with the present invention, and is similar to those of FIGS. 10A and 11A.

The configuration of FIG. 12A from those of FIGS. 10A and 11A in that the gate terminal of the n-channel type MOS transistor NMOS1 is coupled to the fixed voltage VBIAS through a resistor RSP instead of being connecting directly to the fixed voltage VBIAS, and is capacitively coupled to the input terminal for the input pulse VIN through a capacitance CSP.

The following explains the operation of the circuit of FIG. 12A by reference to FIG. 12B.

When the input pulse VIN changes from "L" to "H" at time t1, this voltage change is transferred to the node N4 through the capacitance CSP, and the voltage change at the node N4, that is, the voltage change at the gate of NMOS1, is approximately expressed by the following equation (48).

$$\Delta V = V_H \times CSP / (CSP + CS4) \quad (48)$$

where CS4 represents a parasitic capacitance component which is a capacitance formed at the node N4 minus the capacitance CSP.

The voltage VN4 at the node N4 is expressed by the following equation (49).

$$VN4 = VBIAS + \Delta V \quad (49)$$

After this time, a charge corresponding to a voltage  
5 component beyond the voltage VBIAS is discharged toward the bias voltage BIAS through the resistance RSP, and its time constant is approximately expressed by the following equation (50).

$$\tau = RSP \times (CSP + CS4) \quad (50)$$

10 NMOS is turned ON, the voltage VN1 at the node N1 rises, and when the voltage VN1 rises so high as to satisfy the following equation (51), NMOS1 is cut off and turned OFF.

$$VN4 - VN1 = V_{th} \quad (51)$$

15 Let tcg be time required for the voltage VN1 at the node N1 to reach the value to satisfy the equation (51). Then the voltage VN4 at the node N4 at this time is approximately expressed by the following equation (52).

$$VN4 = VBIAS + \Delta V \times \exp(-tcg/\tau) \quad (52)$$

20 Anyway, since  $VN4 > VBIAS$ , even if VBIAS is selected to be  $VDD/2$ , the amount of current flowing through NMOS3 is larger (i.e., the on-resistance is smaller) than in the case of Embodiment 7, thereby charging a larger amount of charge into the node N1 before the relationship  
25 expressed by the equation (52) is satisfied, and

consequently, the voltage VN2 at the node N2 becomes higher than the voltage VN1 expressed by the equation (42) in Embodiment 7.

Furthermore, it is possible to realize the  
5 relationship of  $VN1 = VH$  by selecting CSP and RSP such that the voltage VN4 expressed by the equation (52) satisfies the following equation (53).

$$VN4 = VBIAS + \Delta V \times \exp(-tcg/\tau) \geq Vth \quad (53)$$

For simplicity, it is assumed that  $VN1 = VH$ , and  
10 a voltage rise at the node N2 can be neglected which has been caused by a current flowing through NMOS3 during tcg.

After that, a relationship expressed by the following equation (54) is realized by a voltage rise  $\Delta VN2$  of the voltage VN2 at the node N2 caused by charging  
15 the node N2 through NMOS3, and the voltage VN1 is higher by the voltage Vth than the voltage expressed by the equation (44) in Embodiment 7.

$$VN1 = VH + \Delta VN2 \times CB/(CB + CS) \quad (54)$$

This means that the gate voltage of NMOS3 is higher  
20 than that in Embodiment 7, and as a result the amount of current charging the node N2 through NMOS3 is increased, and thereby the speed of rise of the voltage VN2 is increased.

Consequently, the voltage level conversion can be  
25 performed in a shorter period of time, and thereby

processing of faster pulses can be realized.

As a modification of this embodiment, the first terminal of NMOS2 having VIN<sub>invert</sub> applied to its gate electrode can be connected to the low-voltage power supply line VSS as in the case of the  
5 modification of Embodiment 7.

#### Embodiment 9

FIG. 13A is a circuit diagram of another embodiment of the voltage level converter VLC fabricated on a surface  
10 of a substrate of the liquid crystal display device in accordance with the present invention.

In the configuration of FIG. 13A, two stages each comprising the circuit of FIG. 11A are coupled in cascade, and a gate terminal of a transistor (the n-channel type  
15 MOS transistor NMOS4 in FIG. 13A) in the second stage corresponding to the n-channel type MOS transistor NMOS1 in the first stage preceding the second stage is coupled to the high-voltage power supply line VDD. Reference characters CB1 and CB2 represent capacitances  
20 corresponding to the capacitance CB in FIG. 11A, and reference characters CS1 and CS2 represent parasitic capacitances at the nodes N1 and N3, respectively. The voltage level converter of this configuration is capable of reducing an effective ON-resistance of the output MOS  
25 (the n-channel type MOS transistor NMOS6) and improving

the speed of charging the load circuit.

FIG. 13B is a timing chart for explaining the operation of the above-described circuit, FIG. 13C illustrates changes of the voltages at the nodes N1 and N2 of FIG. 13A in greater detail, and FIG. 13D illustrates changes of the voltages at the nodes N3 and N4 of FIG. 13A in greater detail.

When the input pulse VIN changes from "L" to "H" at time t1, the node N1 begins to be charged and the voltage VN1 at the node N1 rises. Then when the voltage VN1 rises up to the threshold voltage Vth of NMOS3, NMOS3 is turned ON and the voltage VN2 at the node N2 begins to rise.

When the voltage VN1 becomes (VBIAS - Vth), NMOS is turned OFF and its electrical connection to the input terminal for the input pulse VIN is cut off. Let V1 be the voltage VN2 at the node N2 at this time.

As in the above explanation, let  $\Delta V1$  be (VBIAS - Vth - V1). Then if  $\Delta V1 > v_{th}$ , NMOS3 maintains the ON state, and if the following equation (55) is satisfied, the voltage VN2 at the node N2 rises up to VDD.

$$V_{BIAS} - v_{th} + (V_{DD} - V1) \times (C_{B1} / (C_{B1} + C_{S1})) - V_{DD} \geq v_{th} \quad (55)$$

Here, the time constant for the speed of the voltage rise is approximately expressed by the following equation (56).

$$\tau(t) = R_{ON}(t)(NMOS3) \times (C_{B2} + C_{S2}) \quad (56)$$



where  $R_{ON}(t)(NMOS3)$  represents an ON-resistance of NMOS3.

Here, since an effective current through of NMOS3, that is, its ON-resistance  $R_{ON}(t)(NMOS3)$ , varies with  
5 time, the time constant  $\tau(t)$  is a function of time.

A current  $I_{ds}$  through NMOS3 at time  $t_2$  is approximately expressed by the following equation (57).

$$I_{ds} = A \times (\Delta V_1 - V_{th}) \times (\Delta V_1 - V_{th}) \quad (57)$$

where  $A$  is a constant determined by the structure,  
10 dimensions and others of the MOS transistor.

Since the ON-resistance  $R_{ON}(t)(NMOS3) \propto 1/I_{ds}$ , it is apparent that  $\Delta V_1$  is an important factor in determining the time constant  $\tau(t)$  by the equation (56). That is to say, the larger the voltage  $\Delta V_1$  is selected  
15 to be, the smaller the ON-resistance  $R_{ON}(t)(NMOS3)$  becomes, and consequently, the time constant  $\tau(t)$  is reduced and the speed of the voltage rise in the load circuit is increased.

In this embodiment, in the first stage composed of  
20 NMOS1, NMOS2 and NMOS3, "H" of the input pulse  $V_{IN}$  is raised to the voltage  $V_{DD}$ , and then is supplied as an input voltage to the succeeding stage comprised of NMOS4, NMOS5 and NMOS6. The gate of NMOS4 is coupled to the high-voltage power supply line  $V_{DD}$ , and therefore the turn-off voltage of  
25 NMOS4 becomes  $(V_{DD} - V_{th})$ .

The source of NMOS6 serves as an output terminal of this embodiment and is coupled to the load circuit, and as a result its initial voltage rise becomes slow. Therefore, it is easy to set such that  $\Delta V_2$  indicated in FIG. 13D is made larger than  $\Delta V_1$ , and consequently, the ON-resistance becomes smaller and thereby the speed of rise of the voltage  $V_{N4}$  at the node  $N_4$  is increased.

As a modification of this embodiment, the first terminals of NMOS2 and NMOS5 having  $V_{IN}$  invert applied to their respective gate electrodes can be connected to the low-voltage power supply line  $V_{SS}$  as in the case of Embodiment 7.

#### Embodiment 10

FIG. 14A is a circuit diagram of another embodiment of the voltage level converter VLC fabricated on a surface of a substrate of the liquid crystal display device in accordance with the present invention, and is similar to that of FIG. 13A.

The configuration of FIG. 14A differs from that of FIG. 13A in that a capacitance  $C_P$  is coupled between the gate terminal and the second terminal of the n-channel type MOS transistor NMOS2.

The voltage  $V_{N2}$  at the node  $N_2$  decreases because of the coupling capacitance  $C_P$  when the input pulse  $V_{IN}$

changes from "H" to "L". Since the voltage VN2 at the node N2 is lower than "L" of the input pulse VIN when NMOS3 is in the ON state, the voltage VN1 at the node N1 becomes (VBIAS - Vth), and the voltage VN2 at the node N2 at the time when NMOS1 is turned OFF is lower than that in Embodiment 9.

Therefore,  $\Delta V1$  becomes larger than that in Embodiment 9, and as a result the speeds of rise of the voltages VN2 and VN4 at the nodes N2 and N4 are increased and their rise times are improved. Consequently, the voltage level conversion of pulses of higher frequencies can be realized.

FIG. 14B is a timing chart for explaining the operation of the above-described circuit, FIG. 14C illustrates changes of the voltages at the nodes N1 and N2 of FIG. 14A in greater detail, and FIG. 14D illustrates changes of the voltages at the nodes N3 and N4 of FIG. 14A in greater detail.

As a modification of this embodiment, the first terminals of NMOS2 and NMOS5 having VINinvert applied to their respective gate electrodes can be connected to the low-voltage power supply line VSS as in the case of Embodiment 7.

#### Embodiment 11

FIG. 15A is a circuit diagram of another embodiment of the voltage level converter VLC fabricated on a surface

of a substrate of the liquid crystal display device in accordance with the present invention, and is similar to that of FIG. 14A.

The configuration of FIG. 15A differs from that of FIG. 14A in that the input pulse VIN is supplied to the gate electrode of the n-channel type MOS transistor NMOS1 also, and another n-channel type MOS transistor NMOS7 is added. A second terminal of NMOS7 is coupled to a junction point between the second terminal of the n-channel type MOS transistor NMOS1 and the first terminal of the capacitance CB1, a first terminal of NMOS7 is coupled to the input terminal for the input pulse VIN, and a gate terminal of NMOS7 is supplied with the pulse VINinvert equal in magnitude and opposite in phase with respect to the input pulse VIN.

The voltage level converter of this configuration provides the same advantages as in the case of Embodiment 10, and eliminates the need for the controlling bias voltage VBIAS described in connection with Embodiment 10.

FIG. 15B is a timing chart for explaining the operation of the above-described circuit, FIG. 15C illustrates changes of the voltages at the nodes N1 and N2 of FIG. 15A in greater detail, and FIG. 15D illustrates changes of the voltages at the nodes N3 and N4 of FIG. 15A in greater detail.

As a modification of this embodiment, the first terminals of NMOS2, NMOS5 and NMOS7 having VINinvert applied to their respective gate electrodes can be connected to the low-voltage power supply line

VSS as in the case of Embodiment 7.

Embodiments 6 to 11 have been explained by using n-channel type MOS transistors only for all of thin film transistors constituting the circuits, but it is needless to say that the n-channel type MOS transistor can be replaced by p-channel type MOS transistors with the high-voltage power supply and the low-voltage power supply, and the same advantages of the voltage level converters.

In the above-explained embodiments, the transistors constituting the respective voltage level converters are MOS transistors using  $\text{SiO}_2$  layers, for example, as their gate insulating films, but it is needless to say that they can be replaced by MIS transistors using other insulating films such as silicon nitride layers, for example, as their gate insulating films.

As is apparent from the above explanations, the present invention provides the display device provided with a voltage level converter having a through-current sufficiently suppressed.